TABLE XI. Workers Exposed to Asbestos in Five Cohorts Under Study by the Environmental Sciences Laboratory, Mount Sinai School of Medicine

Location	Industry/occupation	Period	No. of workers currently exposed: Total	Also exposed in previous employment
Metropolitan New York	Brake repair and maintenance	1979–1980	699	104
Groton, Connecticut	Shipyard	1976	1,024	98
Baltimore, Maryland	Shipyard	1979	286	10
Fort Allegany, Pennsylvania	Asbestos products manufacturing	1979	254	21
Quincy, Massachusetts	Shipyard	1979	281	16

TABLE XII. Population at Risk to Asbestos-Associated Disease: Workers Exposed to Asbestos in Selected Occupations and Industries, 1940–1979 (in thousands)

Industries or occupations	1940	New entrants: 1940–1949	1950–1959	1960–1969	1970–1979	Totals
Primary asbestos manufacturing	23	200	103	86	76	488
Secondary asbestos manufacturing	30	324	227	259	308	1,148
Insulation work[a]	17	35	47	38	47	184
Temporary, World War II		9				9
Shipbuilding and repair	157	433	354	434	383	1,761
Temporary, World War II		4,325				4,325
Construction trades	426	1,786	1,452	1,866	1,975	7,505
Railroad engine repair	69	194	26	0	0	289
Utility services	44	223	116	116	129	628
Stationary engineers and firemen	295	1,136	623	549	510	3,113
Chemical plant and refinery maintenance	104	542	260	239	248	1,393
Automobile maintenance	372	1,884	1,099	1,282	1,779	6,416
Marine engineer room personnel (except US Navy)	34	121	46	40	27	268
Totals	1,571	11,202	4,353	4,909	5,482	27,527

[a]Insulators are included here and not in other trades in which they were employed, such as shipbuilding, construction, plant maintenance, or power generation.

bestos insulation production plant is available. These sources can be utilized for comparison with the data obtained from the Social Security Administration and Bureau of Labor Statistics on labor turnover. They can further be utilized to obtain estimates of the distribution of employment times in a given industry by comparing the number of individuals actually employed to those that were known to have been hired in different time periods. The latter quantity is available from the seniority lists as individuals were

assigned sequential clock numbers upon employment. These data are presented in Table XIV and supplement the turnover data obtained otherwise.

One notable feature is that the asbestos products manufacturer has an extremely high turnover during the first month after hire. This occurs because of terminations of individuals during a one-month probationary period. After that time, the man enters the union bargaining unit, and any individual terminations are subject to grievance procedures. While such practices are not universal, they are certainly not unique, and it is expected that in primary and secondary manufacturing an extremely high turnover will result during the first month or two of employment as individuals are screened for their performance and suitability for a job. In contrast, in construction, shipbuilding, automobile maintenance, and other industries that require a skill, the turnover in early periods of time is expected to be less as an individual would have demonstrated professional competence prior to being hired. Further, he would likely be represented by a union before employment with a given employer. Thus, nonarbitratable dismissals are less common.

TABLE XIII. The Average Employment Time of All Individuals Potentially Exposed to Asbestos, 1940–1979

Industry or occupation	Average duration of employment (years) calendar periods 1940–1949	1950–1959	1960–1969	1970–1979
Primary asbestos manufacturing 1.6	1.6	3.5	3.8	4.0
Secondary asbestos manufacturing	2.0	3.5	4.0	3.8
Insulation work	13.7[a]	12.4	15.9	12.5
Shipbuilding and repair	4.3[a]	5.3	4.2	4.6
Construction trades	3.3	8.3	7.5	4.5
Railroad engine repair	4.4	7.7	—	—
Utility services	2.8	5.7	5.7	6.0
Stationary engineers and firemen	2.7	6.3	5.8	5.7
Chemical plant and refinery maintenance	3.7	7.4	8.7	8.1
Automobile maintenance	2.7	6.0	7.7	7.0
Marine engineer room personnel (except US Navy)	4.7	7.4	7.8	6.1

[a]Does not include short-term wartime shipyard workers.

TABLE XIV. Labor Turnover in Selected Industrial Establishments

Establishment	Time period	Number of individuals considered	Number employed by time after hire: 1 year	6 months	2 months	1 month
Shipyard products	1977	1,449	—	73%	80%	—
Asbestos products manufacture	1965–1966	759	37%	—	51%	53%
Asbestos products manufacture	1961–1962	306	42%	—	45%	48%
Asbestos products manufacture	1957–1958	108	27%	—	52%	75%
Plastics production	1961–1962	17	—	100%	100%	100%
Insulation products manufacture	1941–1945	820	38%	53%	82%	93%

A study of workers exposed to brominated chemicals in three plants provides data on the distribution of employment times of all 3,579 individuals employed in the facilities [Wong, 1981]. It substantiates the presence of a large number of individuals with very short employment times. Of all employees, 16.4% worked for less than one month and an additional 28.5% for 1–5.9 months. The full distribution of employment times can be characterized by a two-component decreasing exponential. Thus, the work force can be considered as made up of two groups. The average employment time of one, consisting of approximately 2,200 individuals, was 0.5 years and of the other, with 1,400 individuals, was 11.7 years in good agreement with the data of Table XIII.

Relative Risk by Industry

To calculate the asbestos-related cancer mortality in a given industry or operation, it is necessary to have an absolute or relative measure of exposure for the employee group. While detailed information is not available on the asbestos air concentrations that have been prevalent in previous years in each of the above industries, estimates can be made of the relative risk of death from asbestos exposure on the basis of a variety of other studies. In the calculation of asbestos-related cancer mortality for a given industry or occupation, we will utilize the available data for insulation workers for the dose and time dependence of asbestos cancer. To translate available data for insulation workers to other industries, it is necessary to establish measures of exposure for the different groups considered at risk relative to that of insulation workers. These *relative risks for equal times of employment* will be determined by three indices. The primary one is the directly measured mortality data, especially that of mesothelioma or lung cancer, in an industry or trade. A second is the directly measured average concentrations of asbestos that can be attributed to the work activity. The third is the prevalence of X-ray abnormalities after long-term employment in an industry. Here, we will assume that the percentage of X-ray abnormalities attributable to an exposure circumstance after 20 years of employment will be proportional to the total dose of asbestos inhaled by the workers in that industry. Where the percentage of abnormal X-rays approaches 100%, the relative risks will be determined using the percentages of X-rays having a category 2 or greater abnormality on the ILO U/C scale. Information on these direct and indirect measures is shown in Table XV along with the sources of the various data.

For industries in which none of the above indices are available (construction, railroad steam engine repair) or for which the data are very uncertain, relative risk estimates were made from the numbers of mesotheliomas identified among individuals in different asbestos exposure circumstances compared with the total work force exposed. These data utilized the nationwide survey of mesothelioma in 1972 and 1973 by McDonald and McDonald [1980]. The numbers from this series are shown in Table XVI.

The relative risks, by industry, estimated from all of the above data, are listed in Table XVII. Also Indicated in Table XVII are the principal data sources considered in the relative risk estimates. The data available for the estimates are limited and the estimates are necessarily approximate. For the years 1972–1979, the relative risks for manufacturing, insulation work, shipbuilding, and utility employment will be reduced to 0.1, and those of the other industries (except automobile maintenance) to 0.05 to re-reflect the adoption of control measures. Further, exposures subsequent to 1979 will not be considered.

TABLE XV. Indices of Relative Asbestos Exposure in Selected Occupations and Industries

Industry of occupation	Estimated average fiber concentrations	Relative risk of lung cancer	Percentage of deaths from mesothelioma	Applicable employment period (years)	Percentage of: parenchymal abnormalities 1 +	Percentage of: parenchymal abnormalities 2 +	Percentage of: pleural abnormalities	Applicable employment period (years)
Primary manufacturing	20–40	2.8[a]–6.1[b]	2.6[b]–9.1[a]	1–20 +				
Insulation work	15[e]	4.8[c]	8.7	20 +	85[d]	42[d]	56[e]	20 +
Shipbuilding and repair	2[f]	1.6[g]		2–3	86[h]	17[h]	54[h]	20 +
Chemical plant and refinery maintenance		1.5[i]		15 est	33[j]	3[j]	44[j]	20 +
Automotive maintenance	0.1 0.3[k]				5[k]			10 +
Marine engine room personnel							16–20[l]	15

[a][Nicholson, 1981a.]
[b][Seidman et al, 1979.]
[c][Selikoff et al, 1979.]
[d][Selikoff et al, 1965.]
[e][Selikoff, 1965.]
[f][J. Thorton, quoted in Enterline, 1981.]
[g][Blot et al, 1981.]
[h][Selikoff et al, 1981.]
[i][Hanis et al, 1979.]
[j][Lilis et al, 1980.]
[k][Nicholson, 1982.]
[l][R.N. Jones, 1980.]

TABLE XVI. The Numbers of Mesotheliomas by Work Activity in North America (1960–1972, Canada; 1972, USA)*

Occupation or industry	Number of cases
Primary and secondary manufacturing	21
Insulation work	27
Shipbuilding and repair	21–49[a]
Construction trades	45–76[b]
Railroad engine repair	5
Utility services	
Stationary engineers and firemen	13+
Chemical plant and refinery maintenance	3
Automobile maintenance	1
"Heating trades"	59[c]

*[McDonald and McDonald, 1980].
[a]Highest number only includes some insulators and heating trades workers.
[b]Highest number may include some insulators, shipyard workers or individuals with employment in heating trades.
[c]Includes many individuals that would be assigned to other categories, as stationary engineers and firemen (furnace repair), shipyard employment (welders, steamfitters), utilities (plumbing, heating, boiler work), manufacturing (boilermakers).

TABLE XVII. The Risk of Asbestos Cancer Relative to Insulation Work After 25 Years Employment

Occupation or industry	Risk	Source of data for estimate
Primary manufacturing	1	Group mortality data, exposure measurements
Secondary manufacturing	0.5	Exposure measurements
Insulation work	1	Reference population
Shipbuilding and repair (except insulators)	0.5	Group mortality data, prevalence of X-ray abnormalities
Construction trades[a] (except insulators)	0.15–0.25[b]	No. of mesothelioma cases in general population
Railroad engine repair	0.2	No. of mesothelioma cases in general population
Utility services	0.3	No. of mesothelioma cases in general population
Stationary engineers and firemen	0.15	Prevalence of X-ray abnormalities
Chemical plant and refinery maintenance	0.15	Prevalence of X-ray abnormalities, group mortality data
Automobile maintenance	0.04	Prevalence of X-ray abnormalities, exposure measurements
Marine engine room personnel (except US Navy personnel)	0.1	Prevalence of X-ray abnormalities

[a]See test for percentage of construction population considered at risk.
[b]Risk for years 1958–1972 when the use of sprayed asbestos fireproofing was common.

The relative risks in Table XVII for insulation work, manufacturing, utility services ("heating trades") shipyard employment, and construction yield "population" risks virtually identical to those found by McDonald and McDonald [1980] in their case-control analysis. They found values of 46.0, 6.1, 4.4, 2.8, and 2.6, respectively, for the relative risks of the above populations. Multiplying our equal exposure risks by

the average durations of employment of all workers from 1940 through 1969 (13.2, 2.0, 4.7, 1.9, and 6.4 years, respectively) and further dividing the risk for construction workers by two to account for the 50% of workers to whom we attributed no risk, we obtain for the relative "population" risks the values, 13.2, 1.3, 1.4, 0.95, and 0.5. Adjusting to the McDonald and McDonald [1980] risk of 46 for insulators, we obtain for "population" risks, 46.0, 4.6, 4.9, 3.3, and 1.8.

Lower Risk Population

While we are unable to obtain full data on the distribution of employment times in all industries, the information depicted above allows us to identify a segment of the work force with considerably less exposure to asbestos. Taking a period of employment of two months in primary manufacturing or insulation work as a measure of a low exposure, we have estimated the number of individuals with such an exposure among the 27,500,000 individuals identified previously. This would correspond to a total exposure of 2–3 f-yr/ml (12–18 f/ml × 1/6 yr). The estimates were made assuming 40% of the new hires in primary and secondary manufacturing and 20% of the new hires in other industries left within two months. For longer periods, we utilized an exponential function, $e^{-\beta t}$, for the distribution of employment times where β is the average steady-state permanent separation rate. The period of employment characterizing "lower exposure" for a given industry will be inversely related to the relative risk of the industry (Table XVII). These data are presented in Table XVIII and suggest that 8,700,000 of those potentially exposed to asbestos will have a significantly lower risk by virtue of their short employment period. The extremely large number in automobile maintenance arises because of the low relative risk of asbestos disease in that industry. Thus, individuals with as much as four years of employment in automobile maintenance were included in the estimates that gave rise to Table XVIII.

The data in Table XVIII indicate that an enormous number of individuals are likely to have had *some* exposure to asbestos: 27,500,000 since 1940. Of this number, it is estimated that 21,000,000 were alive on January 1, 1980. (This figure was calculated

TABLE XVIII. The Percentage of Asbestos-Exposed Individuals With Lower Exposure*

	Total exposed		Number with	Percentage with
	1940	1940–1979	lower exposure	lower exposure
Primary asbestos manufacturing	23	465	186	38
Secondary manufacturing	30	1,118	493	43
Insulation work	17	167	33	18
World War II		9	2	20
Shipbuilding and repair	157	1,604	362	20
World War II		4,325	1,303	30
Construction trades	426	7,079	1,842	24
Railroad engine repair	69	220	72	25
Utility services	44	584	141	22
Stationary engineers and firemen	295	2,818	834	27
Chemical plant and refinery maintenance	104	1,289	350	25
Automobile maintenance	372	6,044	3,032	47
Marine engine room personnel	34	234	75	28
Totals	1,571	25,956	8,715	32

Lower exposure is characterized as being less than that equivalent to two months employment in an asbestos factory or as an insulator (approximately 2–3 f-yr/ml). It is *not* to be construed as being without risk.

using procedures detailed in the mortality estimates to follow.) Of those exposed, 18,800,000 of the total and 14,100,000 of those alive on January 1, 1980 were estimated to have had an exposure greater than 2–3 f-yr/ml. Such exposures carry significant risk of asbestos disease (as will be detailed subsequently). Further, some risk of asbestos disease exists for the 6,900,000 alive on January 1, 1980, estimated to have experienced lesser exposures.

CANCER FROM OCCUPATIONAL ASBESTOS EXPOSURE: PROJECTIONS 1965–2030

In recent years, considerable data have accumulated that allow projections to be made of the cancer mortality associated with past exposure to asbestos. These include new information on the dose and time dependence of asbestos-related cancers in various occupational circumstances, an increased awareness of the various trades in which possible asbestos exposure occurred in past years, as well as information on the absolute and relative exposures of these different occupational groups. While the relevant data are less complete than desired, they are sufficient to allow estimates of future asbestos-related mortality to be made. These may be useful in directing priorities for appropriate surveillance and interventive activities that might be undertaken.

The Spectrum of Asbestos-Related Cancer

The spectrum of malignant disease that occurs from asbestos exposure is best seen in data from the mortality study of Selikoff et al [1979] on 17,800 insulation workers. This information is shown in Table XIX in which the numbers of deaths, by

TABLE XIX. Deaths Among 17,800 Asbestos Insulation Workers in the United States and Canada, January 1, 1967–December 31, 1976*

Underlying cause of death	Expected[a]	Observed (BE)	Observed (DC)	Ratio o/e (BE)	Ratio o/e (DC)
Total deaths, all causes	1658.9	2271	2271	1.37	1.37
Total cancer, all sites	319.7	995	922	3.11	2.88
Cancer of lung	105.6	486	429	4.60	4.06
Pleural mesothelioma	b	63	25	—	—
Peritoneal mesothelioma	b	112	24	—	—
Mesothelioma, n.o.s.	b	0	55	—	—
Cancer of esophagus	7.1	18	18	2.53	2.53
Cancer of stomach	14.2	22	18	1.54	1.26
Cancer of colon-rectum	38.1	59	58	1.55	1.52
Cancer of larynx	4.7	11	9	2.34	1.91
Cancer of pharynx, buccal	10.1	21	16	2.08	1.59
Cancer of kidney	8.1	19	18	2.36	2.23
All other cancer	131.8	184	252	1.40	1.91
Noninfectious pulmonary diseases, total	59.0	212	188	3.59	3.19
Asbestosis	b	168	78	—	—
All other causes	1280.2	1064	1161	0.83	0.91

*Number of men: 17,800, man-years of observation: 166,853. From Selikoff et al [1979].
[a]Expected deaths are based upon white male age-specific US death rates of the US National Center for Health Studies, 1967–1976.
[b]Rates are not available, but these have been rare causes of death in the general population.
(BE) Best evidence; number of deaths categorized after review of best available information (autopsy, surgical, clinical). (DC) Number of deaths as recorded from death certificate information only.

cause, over a ten-year period, are tabulated along with those expected from national rates. Causes of death are characterized both according to those listed on the certificates of death (DC) and according to the best evidence (BE) available from a review of autopsy protocols, medical records, and pathological specimens. For most causes of death, the agreement is relatively good, but for mesothelioma and asbestosis, considerable differences exist. Because deaths from these causes are rare in the absence of asbestos exposure, their misdiagnosis has little effect upon general population rates. However, as they are common causes of death among asbestos-exposed workers, their misdiagnosis can seriously affect determination of asbestos mortality. Thus, the "best evidence" mortality will be used for the estimate of asbestos-related cancers. However, as we will attribute all excess cancer among insulators to their asbestos exposure (see below), the overall results will not differ greatly from that using certificate of death diagnosis. Higher rates of death at one site (as mesothelioma) will be balanced by lower rates at another (as pancreas).

In addition to mesothelioma and cancer of the lung, cancer of the stomach, colon, rectum, esophagus, larynx, pharyx, buccal cavity, and kidney are each elevated significantly compared with rates expected for these sites in the general population. (This group will be referred to subsequently as "asbestos-related" malignancies.) Opportunity for fiber contact with the epithelial surfaces of the lung and gastrointestinal tract is clearly evident. Exposure to the mesothelial tissue and kidney can occur as fibers readily penetrate into lung lymphatics and reach the pleural mesothelium ("pleural drift") or can be transported to the kidney or peritoneal mesothelium. Similarly, fiber dissemination occurs to other extrapulmonary organs, such as brain, liver, spleen, etc [Langer, 1974]. While excesses at these other sites are not of statistical significance for individual malignancies, the category "all other cancers" is elevated at a high level of significance ($p < 0.0001$), and we will attribute these excess malignancies to asbestos exposure as well. Their contribution accounts for less than 8% of the total excess cancer compared with the contribution of lung cancer, 56%; mesothelioma, 26% and the other above specified "asbestos-related tumors," 10%.

The Time Course of Asbestos-Related Cancer

The time course of asbestos-related mortality from bronchogenic carcinoma is shown in Figure 1 according to ages for individuals exposed initially between ages 15 and 24, and 25 through 34. As can be seen, the two curves of relative risk, according to age, rise with the *same* slope and are separated by approximately ten years. This suggests that the *relative risk* of developing lung cancer is independent of age and of the pre-existing risk at the time of exposure. In contrast, had one plotted the *added risk* of cancer, the slope and the amount for the group first exposed at older ages would have been two to four times greater than for those exposed at younger ages. If one combines these data and plots them according to time from onset of exposure, the curve of Figure 2 is obtained. A linear increase with time from onset of exposure is seen for 35 to 40 years (to about the time when many insulators terminate employment). After 40 years the relative risk falls significantly, rather than remaining constant after cessation of exposure as might be expected from the linear increase with continued exposure. The decrease is not solely the result of the elimination of smokers from the population under observation as a similar fall occurs for those individuals who were smokers in 1967. (In calculating the relative risk of lung cancer in smokers, smoking-specific data from the American Cancer Society study of one million people were utilized [Hammond, 1966].) Selection processes, such as differing exposure patterns or differing individual

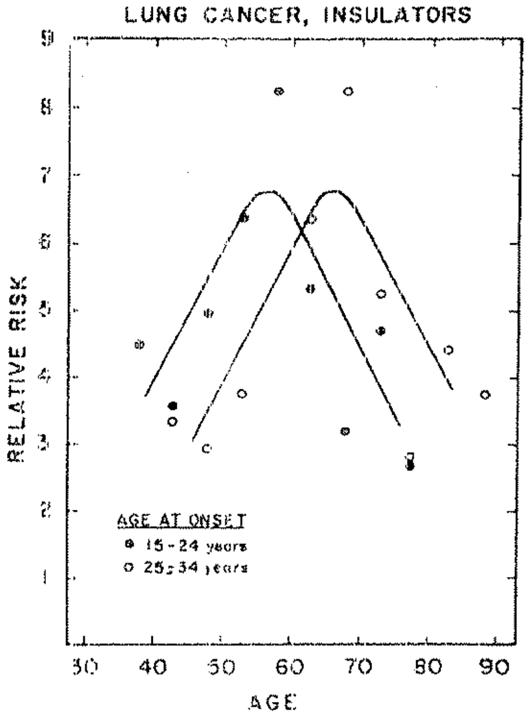

Fig. 1. The ratio of observed to expected deaths from lung cancer among insulation workmen according to age and age at onset of employment.

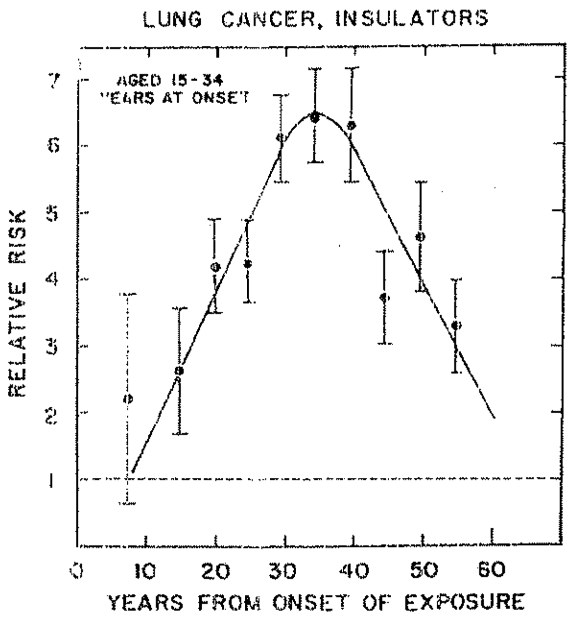

Fig. 2. The ratio of observed to expected deaths from lung cancer among insulation workmen according to time from onset of employment.

biological susceptibilities may play a role, but the exact explanation for the effect is not understood. It is, however, a general phenomenon seen in many mortality studies.

The early portion of the curve of Figure 2 is remarkable in two aspects. Firstly, it shows a linear increase in the relative risk of lung cancer according to time from onset of exposure. This suggests that the dose of asbestos received in a given period of time increases the risk of cancer by an amount that is proportional to that which existed in the absence of exposure. This increased *relative risk* is proportional to the dose of inhaled asbestos, which in turn is proportional to the time worked. Thus, the linear rise in Figure 2. However, the linear rise can occur only if the increased relative risk that is created by a given dose of asbestos continues to multiply the "background" risk for several decades (at least until age 60), even though the background risk will increase tenfold or twentyfold in 30 years. Secondly, the extrapolated line through the observed data points crosses the line of relative risk equal to one (that expected in an unexposed population) very close to the onset of exposure. At most, the line might be adjusted so that it passes through the relative risk of one line at a time from onset of exposure of about ten years. (Note that we are plotting the relative risk of death. Irreversible malignancy would have been initiated several years earlier, since usually one or two years elapse between identification of lung cancer and death, and it is likely that a malignant growth was present, unseen, for at least one or two years before becoming clinically evident.) This means that an increased relative risk appropriate to a given exposure is achieved very shortly after the exposure takes place. However, if there is a low risk in the absence of asbestos exposure, as in young workers, cancers that will arise from that increased relative risk may not be seen for many years or even decades until the background risk becomes significantly greater.

The same two points, 1) that the effect of an exposure to asbestos is to multiply the pre-existing risk of cancer in the exposed population and 2) that the multiplied risk

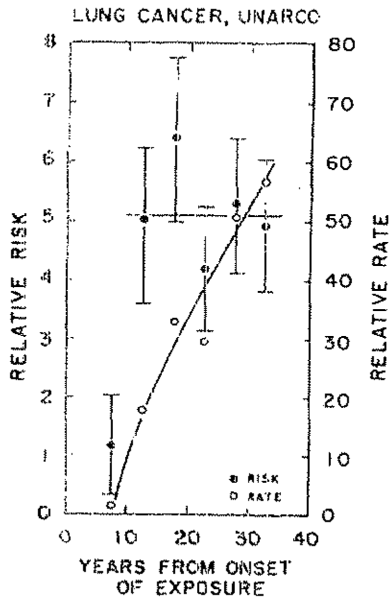

Fig. 3. The ratio of observed to expected deaths from lung cancer and the relative lung cancer mortality rates among asbestos insulation production employees according to time from onset of employment.

becomes manifest in a relatively short time, can also be seen in the mortality from lung cancer in a study of Seidman et al [1979]. Figure 3 depicts the time course of the mortality from lung cancer of a group (UNARCO) exposed for short periods of time, beginning five years after onset of exposure. As 77% were employed for less than two years, exposure largely ceased prior to the follow-up period. As can be seen, a rise to a significantly elevated relative risk occurs within ten years, and then that increased relative risk remains constant throughout the observation period of the study. Furthermore, the relative risk from a specific exposure is independent of the age at which the exposure began. This is seen in Table XX, where the relative risk of death for lung cancer for individuals exposed for less than and greater than nine months is listed according to the age at entrance into a ten-year observation period. Within a given age category, the relative risk is similar in different decades of observation, as we saw before in Figure 3 with the overall data. However, the relative risk also is independent of the age decade at entry into a ten-year observation period. (See lines labelled "All" in each exposure category.) There is some reduction in the oldest groups. This can be attributed to the same effects manifest at older ages in insulators or to relatively fewer cigarette smokers that might be present in the 50-59 year observation groups because of selective mortality.

In the calculation of asbestos-related cancer, the time course of nonmesothelial cancer will be treated as follows. The increase in the relative risk of lung cancer will begin 7.5 years after onset of exposure and increase linearly, following the line of Figure 2 for the number of years a specified group is employed. After a period equal to the average duration of employment, the relative risk will remain constant until 40 years from onset of exposure, after which it will linearly decrease to one over the subsequent three decades. The magnitude of the increase will be equal to that of Figure 2 for insulators and factory employees. The rate of increase for other groups will be proportional to their estimated exposure relative to that of insulators. The same time course

TABLE XX. Relative Risk of Lung Cancer During Ten-Year Intervals at Different Times From Onset of Exposure*

Years from onset of exposure	Age at start of period 30-39	40-49	50-59
	Lower exposure (<9 months)		
5	0.00 [0.35]	3.75 (2)	0.00 [3.04]
15	6.85 (1)	4.27 (3)	2.91 (4)
25	—	2.73 (2)	4.03 (6)
All	3.71 (1)	3.52 (7)	2.58 (10)
	Higher exposure (>9 months)		
5	0.00 [0.66]	11.94 (4)	9.93 (8)
15	19.07 (2)	11.45 (5)	5.62 (5)
25	—	13.13 (6)	7.41 (8)
All	11.12 (2)	12.32 (16)	7.48 (21)

*From Seidman et al [1979].
( ) = Number of cases.
[ ] = No cases seen. Number of cases "expected" on the basis of the average relative risk in the overall exposure category.

will be used for all other nonmesothelial tumors with the magnitude of the increase in insulators being adjusted by the observed frequency of these tumors compared with that expected and that of other groups by their estimated exposure relative to insulators as well.

The treatment of the time course of mesothelioma differs from that of lung cancer and other malignancies in that there is no background rate in the absence of asbestos exposure with which to compare the asbestos-related risk. Thus, it is necessary to utilize absolute risks of death. Figure 4 shows the risk of death of mesothelioma according to age for individuals exposed first between ages 15 and 24 and between ages 25 and 34 as in Figure 1. As can be seen, these data, while somewhat uncertain because of small numbers, roughly parallel one another by ten years as did the increased relative risk curves for lung cancer. Thus, the absolute risk of death from mesothelioma appears to be directly related to onset of exposure and is independent of the age at which the exposure occurs. The risk of death from mesothelioma among the insulation workers is plotted according to time from onset of exposure on the right side of Figure 4. It increases as the fourth or fifth power of time from onset of exposure for about 40 or 50 years. Thereafter, data are scanty and information on the time course is not reliable. For the purposes of analyzing the mortality experience among various groups of workers, the relationship depicted in Figure 4 will be used. After 45 years from onset of exposure, we will consider the risk of death from mesothelioma to remain constant at 1.2 per 100 person-years for insulation workers employed for 25 or more years. For insulators employed for shorter periods, the risk will be reduced by the fraction of 25 years worked. For other exposed groups the risks depicted in Figure 4 will be reduced by the relative exposure of the group compared with insulators and by the fraction of 25 years that a population is exposed.

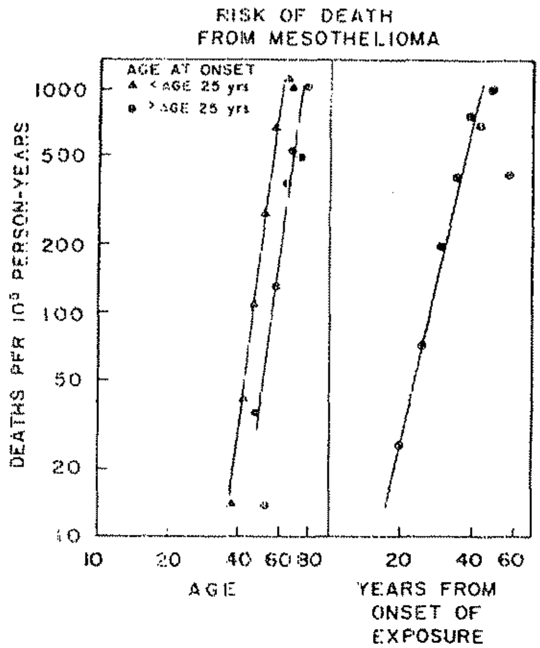

Fig. 4. The death rates for mesothelioma among insulation workmen according to age and age at onset of employment and according to time since onset of employment.

Dose-Response Relationships for Asbestos-Related Cancer

Four recent studies have demonstrated that the risk of lung cancer increases linearly with dose over a fairly wide range of exposures [Dement et al, in press; Henderson and Enterline, 1979; Liddell et al, 1977; Seidman et al, 1979]. Unfortunately, the studies are not directly comparable. For three, the measure of dose was the exposure to asbestos and other dusts in terms of millions of particles per cubic foot (mppcf) times the duration of exposure. This exposure categorization is highly dependent upon the proportion of nonfibrous material in the aerosol being considered. Some relationships between particle counts and fiber concentrations in fibers longer than 5 micrometers per milliliter (f/ml) have been provided in the literature, but these are tenuous at best, based as they are upon a limited number of observations. Further, the study of Henderson and Enterline [1979] was limited to retirees over age 64 of a major asbestos products manufacturer in the United States. As was seen in Figure 2, observations of exposed groups begun late in life can differ considerably from those in which follow-up starts at younger years (as, for example, at age 40–45, 20 years after onset of employment). In the fourth study, that of Seidman et al [1979], exposure characterization involved the use of data from plants other than that in which the mortality experience occurred. A discussion of some of the differences of the slopes of the dose-response functions obtained in these studies has been made elsewhere [Nicholson, 1981a]. The important aspect is the linearity of effect with increasing amounts of asbestos inhaled.

In the analysis which follows, it is not necessary that one fully understand the reasons for the differences in the slopes of dose-response relationships in mining and various manufacturing operations as the relative risks in different industries will be based largely upon the observed mortality experience in those industries or upon a comparison of the number of cases of mesothelioma or excess lung cancers in different work activities. In this subsequent comparison, however, we will utilize a linear dose-response relationship to adjust for different periods of employment. While the evidence of linearity is strong for lung cancer, we will assume that it also obtains for mesothelioma and other malignancies. The evidence for this is more limited, but an analysis of the risks of mesothelioma according to time of employment in the study of Seidman et al would suggest that it is true for that tumor as well. For example, 0 of 215 deaths from mesothelioma occurred from less than 6 months exposure, 3 of 82 from 6 to 11 months exposure, 4 of 74 from 1 to 2 years exposure, and 7 of 63 from more than 2 years exposure.

Calculation of Asbestos-Related Mortality

As discussed previously, for those trades in which workers have possible asbestos exposure, estimates were made of the number of employees potentially at risk, the relative exposure of those workers compared with insulators, the average employment time of individuals entering a particular trade or industry, and the age distribution of new hires in the various trades or industries. The asbestos-related cancer mortality was calculated as follows. For those employees entering a trade subsequent to 1940, the above data from Table XII were utilized to obtain the number of new entrants into an industry during different periods of time. The age distribution of new manufacturing employees of 1960 (Table XXI) was used to calculate age-related mortality of new entrants into a trade or industry. This distribution also was found in new hires during 1974 at a major northeast US shipyard (E. Christian, personal communication). For each quinquennium at entry, the appropriate age, calendar year, and asbestos risk specific rates were applied to calculate the excess lung and other cancer mortality, the risk

of death from mesothelioma, the total mortality (based on US national rates for the entry quinquennium and all subsequent quenquennia until the year 2030 (assuming 1975–1979 rates to apply to the year 2030). This was done for each five-year period of entry, 1940–1980, and the calculated numbers summed for each calendar quinquennium, 1940–2030. For those employed in 1940, the appropriate age distribution for an industry or trade in 1940, as given by the US census, was used. For those employed in 1940, it was assumed that onset of asbestos exposure occurred at age 22.5 or 1930 for those 32.5 years or older in 1940.

The excess, nonmesothelial cancer mortality was calculated using the time dependence displayed in Figure 2 with the assumption that the manifestation of risk from a given exposure will first take place 7.5 years after its occurrence and increases linearly until 7.5 years after cessation of exposure. The risks of death from mesothelioma were calculated using the data of Figure 4, adjusted for each industrial group, with risk assumed to be constant after 45 years from first exposure. Account was taken of the different periods of exposure for each group in each decade, as indicated in Table XIII. Calculations were made using US white male rates. Some blacks and some women would have been employed in the industries under consideration, although their numbers would have been small. Were data available on the number of blacks and women, the use of black male rates would have increased the number of nonmesothelioma cancers and the female rates would have decreased the number, resulting in only a small change from these data.

The results of such calculations are shown in Table XXII through XXV, which list the average annual excess number of lung cancers, mesotheliomas, gastrointestinal, and other asbestos-related cancers, and total excess cancer attributable to asbestos exposure in each quinquennium from 1965 to 2030 for the populations in Table XII. In these tables the average annual mortality in each quinquennium is listed by the midyear of the period. As can be seen, the dominant contributors to the asbestos-related disease are the shipbuilding and construction industries. Industries directly involved in the manufacturing of asbestos products or with the application of insulation material contribute a significantly smaller proportion to current asbestos disease and that to be expected for the next two decades.[2]

It is instructive to look at a display of the number of mesotheliomas and asbestos-related cancers in the shipbuilding industry from the year 1940 to the year 2000. While the total number of malignancies are necessarily uncertain, the data on the time course of the cancers that will occur are relatively good. These data are shown in Figures 5 and 6 for the populations first employed prior to 1940, during World War II, and subsequent to 1945. As can be seen, the relative importance of the wartime and postwar exposures are roughly equal, even though a considerably greater number of individuals were employed in World War II. This, of course, occurs because of the relatively short periods of work for the wartime group. Further, while the exposures in the construction industry are more uncertain, the important disease experience is also ahead of us in

[2]A preliminary report on this research has been presented elsewhere (W.J. Nicholson, G. Perkel, I.J. Selikoff, and H. Seidman. Cancer from occupational asbestos exposure: Projections 1980–2000. Banbury Report 9, Cold Spring Harbor Laboratory, 1981, pp 87–111). In that publication, an estimate was presented of the population at risk from asbestos exposure since 1940 (13,200,000) and projections of asbestos-related mortality (8,770 deaths in 1982 to 9,750 in 1990). The estimates of the population exposed to asbestos presented there, however, did not fully account for the extremely high turnover in workplace employment that we have discussed here. However, as the mortality estimates did not depend on the total population exposed they are virtually identical to those presented here.

that industry, largely because of the extensive use of asbestos in spray fireproofing materials between 1958 and 1972. A measure of the overall future disease experience can be seen in Figure 7, which depicts the projected annual mesothelioma deaths from 1940 to the year 2000. Of all mesotheliomas that are estimated to occur between the years 1940 and 2000, about one third have occurred to date.

The number of mesotheliomas estimated by this procedure is approximately 40% greater than those that would be estimated to occur nationwide using data of the SEER program for white males during 1978 [R. Connelly, National Cancer Institute, personal communication, 1981]. Here, initial data (with one center not analyzed) report 98 mesothelioma deaths in nine of the ten SEER areas. As they represent approximately a

TABLE XXI. Age Distribution of Employees Hired During 1965 Who Were Not Working January 1, 1965*

Age	Number (in thousands)	Percent in age interval	Percent of shipyard workers in age interval[a]
18–19	892	15.[illegible]	17.8
20–24	1,6[illegible]4	27.3	31.6
25–34	1,431	24.3	27.6
35–44	861	14.6	12.0
45–54	588	10.0	6.1
55–64	361	6.[illegible]	2.9
65 +	146	2.5	0.0

*Data from Bureau of Labor Statistics [1965].

[a]Based on 478 new hires during 1974. Data from Christian, Sec. Local 5, Industrial Union of Marine and Shipbuilding Workers of America (personal communication, 1981).

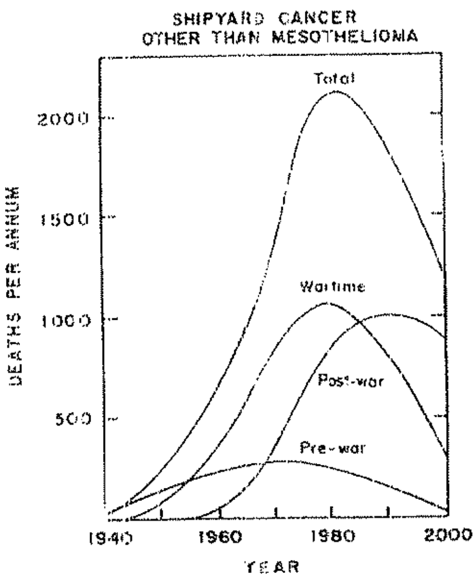

Fig. 5. The estimated and projected numbers of mesothelioma deaths per annum from past asbestos exposure from 1940 through 1999 among three groups of shipyard employees (those employed in 1940 or earlier, those employed during World War II, and those employed subsequent to World War II).

10% sample of the US population, the national estimate of cases for 1978 would exceed 1,000. This is to be compared with our estimate of 1,400 for the quinquennium 1976–1980 (and for the year 1978). In this comparison, however, it should be noted that the information used for the estimate of asbestos-related cancers in this work relied upon data that identified asbestos malignancy following analysis of all medical evidence and after a review of all pathological material available. The SEER program, on the other hand, used records-based reports with no review of pathological material. Experience has shown that pathological review will identify as mesothelioma many neoplasms initially categorized otherwise [Levine, 1978]. Further, while well representing the shipbuilding industry, the ten SEER areas underrepresent industrial areas and

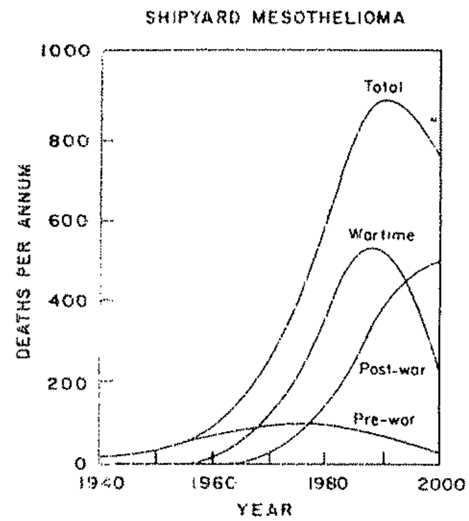

Fig. 6. The estimated and projected numbers of excess asbestos-related cancers per annum from 1940 through 1999 among three groups of shipyard employees (those employed in 1940 or earlier, those employed during World War II, and those employed subsequent to World War II).

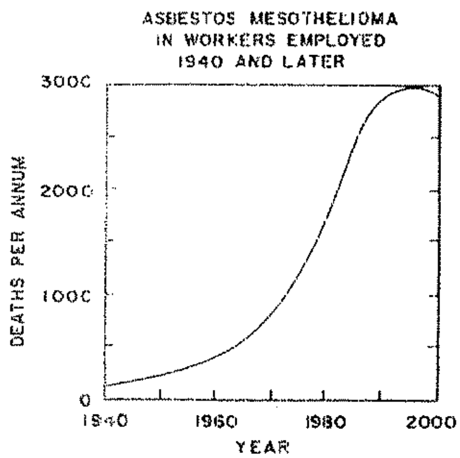

Fig. 7. The estimated and projected numbers of mesotheliomas per annum from 1940 through 1999 from occupational asbestos exposure.

TABLE XXII. The Projected Annual Excess Deaths From All Asbestos-Related Lung Cancer in Selected Occupations and Industries, 1967–2027

Industry or occupation	Number deceased in calendar year												
	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	2022	2027
Primary asbestos manufacturing	129	189	240	270	288	284	260	224	173	122	77	43	20
Secondary manufacturing	146	192	261	321	374	387	377	343	291	228	160	102	56
Insulation work	158	235	319	379	418	421	390	333	299	185	119	68	35
Shipbuilding and repair	847	1,125	1,411	1,479	1,436	1,247	1,027	786	562	401	268	157	78
Construction trades	445	717	1,093	1,405	1,649	1,815	1,893	1,828	1,584	1,235	884	487	228
Railroad engine repair	66	79	88	84	62	55	36	19	8	2	0	0	0
Utility services	82	111	142	161	175	177	168	150	124	95	66	41	22
Stationary engineers and firemen	234	306	380	435	478	493	486	438	378	305	223	147	85
Chemical plant and refinery maintenance	116	163	209	246	267	270	254	224	181	136	93	56	30
Automobile maintenance	100	142	192	240	290	316	340	326	304	266	210	148	90
Marine engine room personnel	21	27	33	35	35	32	28	22	17	12	8	5	2
Totals	2,344	3,286	4,368	5,055	5,472	5,497	5,259	4,693	3,921	2,987	2,108	1,254	646

metropolitan regions that would have had significant construction activities 30 or more years ago. Thus, it is not unexpected that actual US rates may exceed those estimated from the SEER program.

There is observational evidence to support the analytical approach used in these calculations. The data for insulation workers suggest that 650 mesotheliomas and 2,300 excess lung cancers would occur between 1967 and 1976 among members of this craft. This is to be compared with 175 mesotheliomas and 380 excess lung cancers seen among insulators in the single union (The International Association of Heat and Frost Insulators and Asbestos Workers, AFL-CIO) studied by Selikoff et al [1979]. The ratios of 0.27 and 0.17 for the number of deaths among Asbestos Workers Union members to those calculated here is in reasonable agreement with the fraction of all insulators that the union has organized (0.29). The difference in lung cancer and mesothelioma ratios can be attributed to the fact that the insulators organized by this union are older than the entire group estimated to be at risk from 1967 through 1976 and, thus, have a proportionally greater risk of death from mesothelioma than from lung cancer compared to other insulators. Forty-two percent of the Asbestos Workers Union members were 45 years of age or older at the midpoint of the Selikoff et al study. A comparison of the ratios of the calculated 1977 mesothelioma deaths from industries (Table XXIII) with those observed in the study of McDonald and McDonald [1980] (Table XVI) also shows reasonable agreement.

As discussed previously, one third of those estimated to have had a potential exposure to asbestos were exposed for only a short period of time and were believed to have a risk less than that equivalent to that from employment in an asbestos products plant or as an insulator for two months. By calculating the person-years of exposure of the "lower risk population" and comparing the result to the total person-years of employment in each industry the contribution of the lower-risk group to the estimated excess mortality can be obtained. These results are shown in Table XXVI and indicate that 32% of the exposed group will contribute less than 2% of the excess asbestos-related deaths. The numbers are approximate because of uncertainties in the assumed short-term separating rate. They do, however, dramatize the consequences of inclusion of lower exposed individuals in the population at risk.

Asbestosis Deaths

The above estimates are of deaths from malignancy. There will be additional deaths from asbestosis that will occur in individuals exposed to high concentrations over long periods of time. In contrast to the asbestos cancers, deaths from asbestosis generally require considerable fiber exposure. They will largely occur in insulators, manufacturing workers and long-term shipyard employees. They will be fewer than the number of mesothelioma deaths among insulators (perhaps one half to three fourths). Because of the high labor turnover in manufacturing we would estimate that about one third as many deaths will occur from asbestosis as from mesothelioma. A similar ratio is probably appropriate for pre- and post-World War II shipyard workers (short-term wartime work would carry only a limited risk of death from asbestosis). Thus, approximately 200 deaths annually are now occurring from asbestosis (the condition, however, will be contributory to many more deaths). This number will perhaps double during the next two decades and decline thereafter.

TABLE XXIII. The Projected Annual Deaths From Asbestos-Related Mesothelioma in Selected Occupations and Industries, 1967 2027

Industry or occupation	Number deceased in calendar year												
	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	2022	2027
Primary asbestos manufacturing	56	64	80	102	128	149	160	161	147	123	89	59	34
Secondary manufacturing	42	52	70	99	134	167	195	213	214	199	163	123	78
Insulation work	51	65	91	130	173	207	227	229	209	157	128	86	50
Shipbuilding and repair	292	386	542	612	884	865	770	659	541	409	287	201	120
Construction trades	169	193	251	355	495	696	901	1,065	1,176	1,126	882	624	378
Railroad engine repair	38	42	50	60	65	60	45	30	18	7	2	0	0
Utility services	37	41	49	62	76	87	96	99	96	86	68	50	31
Stationary engineers and firemen	120	125	148	168	207	238	259	262	247	214	165	117	71
Chemical plant and refinery maintenance	46	55	70	91	117	138	149	152	145	128	99	71	44
Automobile maintenance	40	48	60	78	100	122	148	172	190	200	190	158	108
Marine engine room personnel	10	11	14	18	19	19	19	18	16	12	9	6	3
Totals	901	1,082	1,425	1,775	2,398	2,748	2,969	3,060	2,999	2,661	2,082	1,495	917

Comparison With Other Studies

Some previous estimates of asbestos-related mortality exceed those discussed here. In the Department of Health, Education, and Welfare estimate that 13%–18% of all cancers in the near future will be asbestos-related, recognition was taken that a large number of individuals were potentially exposed to asbestos, their estimate being 8–11 million compared with ours at 27.5 million, 18.8 million of whom had exposures greater than 2–3 f-yr/ml [Department of Health, Education, and Welfare, 1981]. However, their estimates of the number of heavily exposed individuals was subjective and no explicit adjustment was made for the different employment periods of exposed groups. The estimates by Hogan and Hoel [1981] that up to 12,000 deaths may occur annually from asbestos cancer placed great emphasis upon possible effects from the shipbuilding industry. They, too, subjectively estimated the number of heavily exposed individuals in this trade and did not explicitly account for variations in employment time and may have overestimated the asbestos-related mortality. However, their estimates of the effect of other industries neglected large numbers of individuals with potential exposure. Thus, their estimates for other than shipbuilding would appear to understate the asbestos disease potential [Nicholson, 1981b]. Finally, Blot and Fraumeni [1981] estimate that 120,000 lung cancer deaths will occur (over the population lifetime) from wartime shipyard employment. Our estimate is 25,000. The difference lies largely in our assigning a much lower risk to the very short term (< 1 year) employees.

A lower estimate of 4,000 asbestos cancers annually has been made by Higginson et al [1980] based upon mid-1970 SEER data for mesothelioma and a multiplier of three for other cancers. However, the multiplier depends on time from onset of exposure and population age and exceeded four during the 1970s. (Compare Tables XXII and XXIII.) Further, the previously mentioned limitations of the SEER data apply here. Enterline has also estimated that approximately 4,000 deaths will occur annually [Enterline, 1981]. He attributes 530 lung cancer deaths/yr to primary manufacturing and insulation work, 900 to secondary, 421 to shipyard employment, 212 to auto maintenance, and 438 for other occupations. In addition to lung cancer, he estimates 1,250 other cancers and 333 mesotheliomas will be asbestos-related. The values for primary manufacturing, insulation work, and auto maintenance are similar to our estimates and that for secondary manufacturing considerably more. However, much lower estimates are given for shipbuilding, construction, and other trades. This is in contrast with the finding that a much greater number of mesotheliomas occur in these trades compared with manufacturing and insulation work [McDonald and McDonald, 1980].

Expected Mortality in Asbestos-Exposed Workers

Tables XXII through XXV list the projections for the excess mortality associated with past asbestos exposures. For a given work category, these excess deaths will add to those expected in the absence of exposure but, with the exception of mesothelioma, an "excess" death cannot be distinguished from an "expected" one. As each of these deaths may lead to a claim for compensation or a third party suit, the potential of such cases can greatly exceed the number of excess deaths calculated above. For the heavily exposed (insulators, for example), where the excess deaths exceed those expected, the problem is not a great one. However, for groups with lesser exposure, the total number of lung cancer deaths that could be asbestos-related is very much greater than the numbers in Table XXII. Table XXVII lists the expected lung cancer deaths over the

TABLE XXIV. The Projected Annual Excess Deaths From All Asbestos-Related Gastrointestinal and Other Cancers in Selected Occupations and Industries, 1967–2027

Industry or occupation	Number deceased in calendar year												
	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	2022	2027
Primary asbestos manufacturing	52	59	65	73	78	77	71	60	47	33	21	12	6
Secondary manufacturing	48	60	72	87	102	105	102	93	79	62	44	27	15
Insulation work	57	74	87	103	114	114	106	90	70	50	32	19	9
Shipbuilding and repair	313	354	384	402	390	339	279	214	153	109	73	43	21
Construction trades	164	225	297	383	449	493	514	497	431	336	230	132	63
Railroad engine repair	25	25	24	23	20	15	10	5	2	1	0	0	0
Utility services	30	35	39	44	48	48	46	41	34	26	18	11	6
Stationary engineers and firemen	80	96	103	118	131	134	130	119	103	83	61	40	23
Chemical plant and refinery maintenance	43	51	58	67	73	74	69	61	49	37	25	15	8
Automobile maintenance	36	46	52	66	80	86	90	88	82	72	58	40	24
Marine engine room personnel	8	9	9	10	10	9	8	6	5	3	2	1	1
Totals	856	1,034	1,190	1,376	1,495	1,494	1,425	1,274	1,055	812	564	340	176

TABLE XXV. The Projected Annual Excess Deaths From All Asbestos-Related Cancer in Selected Occupations and Industries, 1967–2027

Industry or occupation	Number deceased in calendar year												
	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	2022	2027
Primary asbestos manufacturing	237	312	385	445	494	510	491	445	367	278	187	114	60
Secondary manufacturing	236	304	403	507	610	659	674	649	584	489	367	252	149
Insulation work	266	374	497	612	705	742	723	652	578	392	279	173	94
Shipbuilding and repair	1,452	1,865	2,337	2,493	2,710	2,451	1,076	1,659	1,256	919	628	401	219
Construction trades	778	1,135	1,641	2,143	2,593	3,004	3,308	3,390	3,191	2,697	1,996	1,243	669
Railroad engine repair	129	146	162	167	147	130	91	54	28	10	2	0	0
Utility services	149	187	230	267	299	312	310	290	254	207	152	102	59
Stationary engineers and firemen	434	527	631	721	816	865	875	819	728	602	449	304	179
Chemical plant and refinery maintenance	205	269	337	404	457	482	472	437	375	301	217	142	82
Automobile maintenance	176	236	304	384	470	524	578	586	576	538	458	346	222
Marine engine room personnel	39	47	56	63	64	60	55	46	38	27	19	12	6
Totals	4,101	5,402	6,983	8,206	9,365	9,739	9,653	9,027	7,975	6,460	4,754	3,089	1,739

years 1965–2030 (assuming 1978 rates for subsequent years). As can be seen, the expected numbers exceed the excess by nearly six times. Even if the 32% of individuals with lower exposure are excluded from consideration, the ratios of expected to excess range from 0.4 to 11.7.

Figure 8 shows the distribution of excess lung cancers expected between 1980 and 2030 according to equivalent insulator-years of exposure. (An insulator-year of exposure is that which would create the same risk as employment as an insulator for one year). The approximate exposure for a doubling of lung cancer risk is also indicated. Of the excess lung cancers, 50% occur in individuals with more than this doubling exposure. The total number of lung cancers is also shown for this group and is about 60% more than the excess due to asbestos exposure. For lesser exposures, the curve of the total cancer rises extremely steeply because of the large number of exposed individuals. At the peak of the asbestos related lung cancer curve, the total lung cancer curve would be four times higher. Parenthetically, the exposure distribution of mesothelioma cases will be similar to that of the excess lung cancers.

As mentioned previously at a given exposure level an "excess" death cannot be distinguished from an "expected" one. The problem, however, extends even across exposure levels. Many individuals with less than 5 insulator-years of exposure will have abnormal X-rays, and a significant percentage with greater exposure will have normal X-rays. This follows from the finding that more than 30% family contacts of

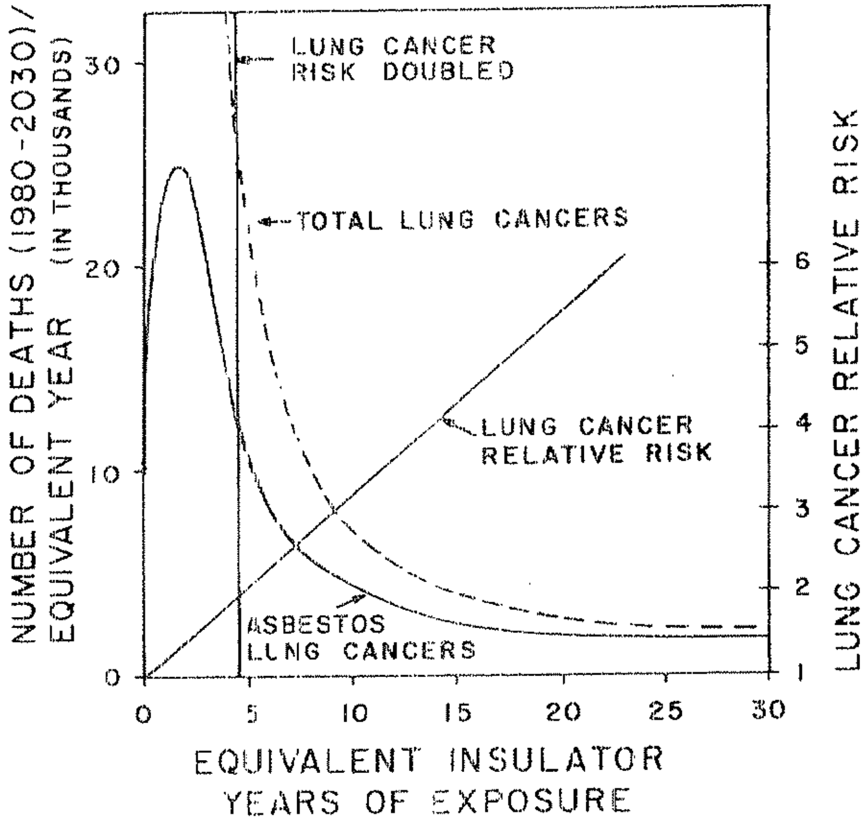

Fig. 8. The distribution of excess lung cancers expected between 1980 and 2030 according to equivalent insulator-years of exposure. (An insulator-year of exposure is that which would create the same risk as employment as an insulator for one year.)

TABLE XXVI. Percentage of Asbestos-Related Cancers That Occur Among Those With Lower Exposure Who Were Exposed After January 1940*

Industry or occupation	Percentage of deaths
Primary asbestos manufacturing	1.2
Secondary manufacturing	1.3
Insulation work	0.1
Shipbuilding and repair	1.9
Construction trades	1.0
Railroad engine repair	1.8
Utility services	0.8
Stationary engineers and firemen	1.8
Chemical plant and refinery maintenance	1.0
Automobile maintenance	12.4
Marine engine room personnel	2.3

*Lower exposure is considered to be less than 2-3 f-yr/ml. The overall contribution to mortality of all individuals with lower exposure is 1.9%.

asbestos factory workers (Anderson et al, 1979) and insulators (Nicholson et al, to be published) have asbestos related X-ray abnormalities (20-30 years after onset of less than 5 equivalent years of exposure) and that a fair number of insulators with 20 or more years in the trade have normal X-rays. Pulmonary function tests are even less revealing. While procedures based on exposure or on clinical evidence of exposure are possible, the allocation of compensation resources to the deserving individuals is clearly an enormously difficult scientific problem. It is an even more difficult social problem.

CONCLUSIONS

Estimates have been made of the numbers of cancers that are projected to result from past exposures to asbestos in a number of occupations and industries. Only those potentially exposed by virtue of their employment have been considered. Additional deaths will result from exposure among family contacts (household contamination), from environmental exposures, from exposure during consumer use of asbestos products, and from exposure while in the Armed Forces, particularly in engine rooms of naval ships. No estimates have been made of deaths resulting from asbestosis. These estimates indicate that:

1. From 1940 through 1979, 27,500,000 individuals had potential asbestos exposure at work. Of these, 18,800,000 had exposure in excess of that equivalent to two months employment in primary manufacturing or as an insulator (>2–3 f-yr/ml). 21,000,000 of the 27,500,000 and 14,100,000 of the 18,800,000 are estimated to have been alive on January 1, 1980.
2. Approximately 8,200 asbestos-related cancer deaths are currently occurring annually. This will rise to about 9,700 annually by the year 2000.
3. Thereafter, the mortality rate from past exposure will decrease but still remain substantial for another three decades.

TABLE XXVII. Expected Lung Cancer Deaths in Selected Occupations and Industries, 1967–2027

Industry or occupation	Number deceased in calendar year												
	1967	1972	1977	1982	1987	1992	1997	2002	2007	2012	2017	2022	2027
Primary asbestos manufacturing	230	327	435	528	604	646	642	588	499	400	308	238	186
Secondary manufacturing	424	628	870	1,100	1,297	1,446	1,518	1,497	1,394	1,237	1,047	833	605
Insulation work	67	97	132	162	187	204	210	203	187	164	138	109	79
Shipbuilding and repair	4,420	5,956	7,550	8,694	9,202	8,553	7,541	5,522	3,595	2,188	1,478	1,144	800
Construction trades	2,501	3,793	5,325	6,761	8,033	9,061	9,648	9,677	9,173	8,246	7,005	5,536	3,942
Railroad engine repair	258	334	404	441	451	421	350	248	143	62	17	20	0
Utility services	316	438	572	684	770	819	827	764	672	566	461	358	256
Stationary engineers and firemen	1,703	2,316	2,969	3,491	3,895	4,114	4,080	3,769	3,253	2,660	2,082	1,557	1,075
Chemical plant and refinery maintenance	736	1,026	1,139	1,576	1,791	1,881	1,870	1,715	1,474	1,205	948	716	504
Automobile maintenance	2,761	3,969	5,358	6,592	7,572	8,231	8,450	8,172	7,543	6,894	5,731	4,646	3,436
Marine engine room personnel	177	236	295	337	361	363	338	288	231	176	133	97	64
Totals	13,593	19,120	25,049	30,366	34,136	35,739	35,374	32,443	28,164	23,798	19,398	15,236	10,947

These projections are from past exposures to asbestos. Over one million tons of *friable* asbestos material are in place in buildings, ships, factories, refineries, power plants, and other facilities. The maintenance, repair and eventual demolition of these facilities provide opportunities for continued significant exposures. If such work is not properly done, or if asbestos is otherwise used with inadequate controls, the burden of disease and death from past exposures will be increased by the environmental exposures of the future.

ACKNOWLEDGMENTS

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REFERENCES

Anderson HA, Lilis R, Daum SM, Selikoff IJ. Asbestosis among family contacts of asbestos factory workers. Ann NY Acad Sci 330:387-399, 1979.

Asbestos Information Association: Comments submitted to the Environmental Protection Agency on the Ambient Water Quality Criteria for Asbestos, 1979.

Association of American Railroads. Statistics of railroads of Class I in the United States, annual, 1940-1960.

Balzer JL, Cooper WL: The work environment of insulating workers. Am Ind Hyg Assoc J 29:222-227, 1968.

Blot WJ, Harrington JM, Toledo A, Hoover R, Heath Jr, CW, Fraumeni Jr, JF: Lung cancer after employment in shipyards during World War II. N Engl J Med 229:620, 1978.

Blot WJ, Fraumeni Jr. JF: Cancer among shipyard workers. Banbury Report #9. Cold Spring Harbor Laboratory, 1981 pp 37-49.

Bonnell JA, Bowker JR, Browne RC, Erskine JF, Fernandez RHP, Massey MO: A review of control of asbestos processes in the Central Electricity Generating Board. XVIII International Congress on Occupational Health, Brighton, England, 1975.

Bureau of the Census: Census of Manufacturers, Washington, DC, 1939.

Bureau of Labor Statistics: "Employment and Earnings, United States, 1909-1978." BLS Bulletin 1312-11, 1979.

Bureau of Labor Statistics: "Handbook of Methods for Surveys and Studies." US Department of Labor, 1976.

Bureau of Labor Statistics: "Occupational Employment." Report 430, Series, 1,9,10,16,29,55,56,61,81, 1974.

Bureau of Labor Statistics: Occupational mobility of employed workers. Special Labor Force Report 84, 1965.

Bureau of Labor Statistics: Occupational employment in the construction industry, June 1978 (unpublished).

Bureau of Labor Statistics: "Tomorrow's Manpower Needs." App. A., US Department of Labor, vol 1, 1969a.

Bureau of Labor Statistics: "Tomorrow's Manpower Needs." US Department of Labor, vol 4, 1969b.

Bureau of Labor Statistics: Wartime employment, production, and conditions of work in shipyards. BLS Bulletin 824. US Government Printing Office. Washington, DC, 1945.

Christian E: Sec. Local 5, Industrial Union of Marine and Shipbuilding Workers of America. Personal communication, 1981.

Connelly, R: National Cancer Institute. Personal Communication, 1981.

Daly AR, Zupko AJ, Hebb JL: Technological feasibility and economic impact of OSHA proposed revision to the asbestos standard. Roy F. Weston Environmental Consultants-Designers, prepared for Asbestos Information Association/North America, Washington. DC, 1976, vol 2.

DeHague GR. International Association of Machinists. Personal communication, November 14, 1980.

Dement JM, Harris Jr, RL, Symons MD, Shy C: Estimates of dose-response for respiratory cancer among chrysotile asbestos textile workers. Presented at Fifth Int Conf on Inhaled Particles, Cardiff, Wales, Sept. 1980 (in press).

Dept Health, Education, and Welfare: Estimates of the fraction of cancer in the United States related to occupational factors. Sept. 15, 1978 (unpublished). Reprinted in Banbury Report #9, Cold Spring Harbor Laboratory, 1981, pp 701-726.

Department of Labor: Industrial Work Survey: Electric and Gas Utilities, February 1978, p. 60, 1979.

Electric and Gas Utilities: Industry Wage Survey. February 1978, BLS, 1979.

Enterline PE: Proportion of cancer due to exposure to asbestos. Banbury Report #9, Cold Spring Harbor Laboratory, 1981, pp 19-36.

Felton JS: Radiographic search for asbestos-related disease in a naval shipyard. Ann NY Acad Sci 330: 341-352 1979.

Ferris Jr, BG, Ranadine MV, Peters JM, Murphy RLH, Burgess WA, Pendergrass HP: Prevalence of chronic respiratory disease. Arch Environ Health 23:220-225, 1971.

Fischbein A, Rohl AN, Langer AM, Selikoff IJ: Drywall construction and asbestos exposure. Am Ind Hyg Assoc J 40:402-407, 1979.

Fleisher WE, Viles FJ, Glade RJ, Drinker P: A health survey of pipe covering operations in construction naval vessels. J Ind Hyg Tox 28:9, 1946.

Fontaine JH, Trayer DM: Asbestos control in steam-electric generating plants. Am Ind Hyg Assoc J 36: 126-130. 1975.

Galloway LE: Interindustry Labor Mobility in the United States 1957 to 1960. US Department of Health, Education and Welfare, 1967.

Hammond EC: Smoking in relation to death rates of one million men and women. In: "Epidemiological Study of Cancer and Other Chronic Diseases." Natl Cancer Inst Monogr 19:172, 1966.

Hanis NM, Stavraky KM, Fowler JL: Cancer mortality in oil refining workers. J Occup Med 21:261, 1979.

Harries PG: Asbestos hazards in naval dockyards. Ann Occup Hyg 11:136, 1968.

Henderson VI, Enterline PE: Asbestos exposure: Factors associated with excess cancer and respiratory disease mortality. Ann NY Acad Sci 330:117, 1979.

Higginson J, Bahar JC, Clemmesen H, Demapoulos H, Garfinkel L, Hirayama T, Schottenfeld D: Proportion of cancers due to occupations. Prev Med 9:180, 1980.

Hickish DE, Knight KL: Exposure to asbestos during brake maintenance. Ann Occup Hyg 13:17-21, 1970.

Hill Jr, AB: International Union of Operating Engineers. Personal communication, April 29, 1980.

Hirsch A, DiMenza L, Carre A, Harf A, Pedriget S, Cooreman J, Bignon J: Asbestos risk among full-time workers in an electricity-generating power station. Ann NY Acad Sci 330:137-145, 1979.

Hogan MD, Hoel DG: Estimated risk associated with occupational asbestos exposure. Risk Analysis 1:67-76, 1981

International Association of Heat and Frost Insulators and Asbestos Workers. Unpublished data (R. Steinfurth, personal communication).

Interstate Commerce Commission: Interstate Commerce Transportation Statistics in the U.S. Part I. Statistical Abstract. Annual.

Jones H: International Union of Operating Engineers. Personal communication, March 3, 1980.

Jones RN: Shipboard asbestos exposure: Hearings before the Subcommittee on Coast Guard and Navigation. US House Committee on Merchant Marine and Fisheries, Serial No. 96-41. Washington, DC, 1980, pp 229-232.

Kaminski R, Geissert KS, Dacey E: Mortality analysis of plumbers and pipefitters. J Occup Med 22:183-189, 1980.

Langer AM: Inorganic particles in human tissues and their association with neoplastic disease. Environ Health Perspect 9:229, 1974.

Lawton GM: Paper on the US Navy asbestos programs and problems. Armed Forces Epidemiological Board, Ad Hoc Subcommittee on Asbestos-related Health Problems. September 29, 1977.

Levine RJ (ed): "Asbestos: An Information Resource." DHEW Publication (NIH) 79-1681, 1978.

Lewinsohn HC, Kennedy CA, Day JE, Cooper PH: Dust control in a conventional asbestos textile factory. Ann NY Acad Sci 330:225-241, 1979.

Liddell FDK, McDonald JC, Thomas DC: Methods of cohort analysis appraised by application to asbestos mining. J R Statist Soc A 140-649, 1977.

Lieben J, Pistawka H: Mesothelioma and asbestos exposure. Arch Environ Health 14:559, 1967.

Lilis R, Daum S, Anderson H, Andrews G, Selikoff IJ: Asbestosis among maintenance workers in the chemical industry and oil refinery workers. In: Biological Effects of Mineral Fibers. International Agency for Research on Cancer, 1980.

Lorimer WV, Rohl AN, Nicholson WJ, Selikoff IJ: Asbestos exposure of brake repair workers in the United States. Mt Sinai J Med 43:207-218, 1976.

Love E: Maritime Administration, US Department of Commerce. Personal communication, Feburary 27, 1976.

Mancuso TF: "Help for the Working Wounded." International Association of Machinists, Washington, DC, 1976.

Maritime Administration, US Department of Commerce: Seafaring employment, ocean-going commercial ships. 1,000 gross tons and over (unpublished).

Marsh J: Director of Environmental Affairs, Raybestos Manhattan, Trumbull, CT. Personal communication.

McDonald AD, McDonald JC: Malignant mesothelioma in North America. Cancer 46:1650, 1980.

Meylan WM, Howard PH, Lande SS, Hantchett A: Chemical market input/output, analysis of selected chemical substances to assess sources of environmental contamination: Task III: Asbestos. Syracuse Resource Corp., prepared for USEPA, Washington, DC, August 1978.

Murphy RLH, Ferris BG, Jr, Burgess WA, Worcester J, Gaensler EA: Effects of low concentrations of asbestos: Observations in shipyard pipe coverers. N Engl J Med 285:1271-1278, 1971.

National Institute for Occupational Safety and Health: Criteria for a Recommended Standard: Occupational Exposure to Asbestos. HMS 72-10267. US Government Printing Office, Washington, DC, 1972.

National Institute for Occupational Safety and Health. Unpublished data. (R. Zumwalde, personal communication).

National Institute for Occupational Safety and Health, National Occupational Hazard Survey, 1972-1974. (Unpublished data on SIC code sequence within alphabetized hazard description).

Newhouse ML, Thompson H: Mesothelioma of the pleura and peritoneum following exposure to asbestos in the London area. Br J Ind Med 22:261-269, 1965.

Nicholson WJ: Insulation Hygiene Progress Reports 3:1. Mount Sinai School of Medicine, NY, 1975.

Nicholson WJ: Dose-response relationships for asbestos and inorganic fibers. Arb och Hÿlsa 17, 1981a.

Nicholson WJ: Comment: The role of occupation in the production of cancer. Risk Analysis 1:77, 1981b.

Nicholson WJ, Perkel C, Selikoff IJ: Cancer for occupational asbestos exposure: Projections 1980-2000. Banbury Report #9. Cold Spring Harbor Laboratory, pp 87-111, 1981.

Nicholson WJ, Selikoff IJ, Seidman H, Hammond EC: Mortality experience of asbestos factory workers: Effect of differing intensities of exposure. Environ Res (in press).

Nicholson WJ: Health hazards of brake repair and maintenance. Report of the National Institute for Occupational Safety and Health, Contract 210-770-119, 1982.

Nunneley JK: Department of the Navy. Personal communication, April 22, 1980.

NYT (Nov. 15, 1981): The New York Times. Workers tested in cancer study, p. 30.

Office of Management and Budget, Executive Office of the President: Standard Industrial Classification Manual 1972. Washington, DC, 1972.

Polland LD: "The American Merchant Marine and the Asbestos Environment." US Maritime Administration, May 1979 (unpublished).

Raybestos Manhattan Co. unpublished data (J. Marsh, personal communication).

Reitze WB, Nicholson WJ, Holaday DA, Selikoff IJ: Application of sprayed inorganic fiber containing asbestos: Occupational health hazards. Am Ind Hyg Assc J 33:179-191, 1972.

Rohl AN, Langer AM, Wolff MS, Weisman I: Asbestos exposure during brakelining maintenance and repair. Environ Res 12:110-128, 1976.

Seidman H, Selikoff IJ, Hammond EC: Short-term asbestos work exposure and long-term observation. Ann NY Acad Sci 330:61, 1979.

Selikoff IJ, Churg J, Hammond EC: Asbestos exposure and neoplasia. JAMA 188:22, 1964.

Selikoff IJ: The occurrence of pleural calcification among asbestos insulation workers. Ann NY Acad Sci 132:351, 1965.

Selikoff IJ, Churg J, Hammond EC: The occurrence of asbestosis among insulation workers in the United States. Ann NY Acad Sci 132:139, 1965.

Selikoff IJ, Hammond EC: Asbestos-associated disease in United States shipyards. CA-A Cancer J for Clinicians 28(2):87-99, 1978.

Selikoff IJ, Hammond EC, Seidman H: Mortality experience of insulation workers in the United States and Canada. Ann NY Acad Sci 330:91-116, 1979.

Selikoff IJ, Nicholson WJ, Lilis R: Radiological evidence of asbestos disease among ship repair workers. Am J Industrial Medicine 1:9-22, 1981

Selikoff IJ: Disability Compensation for Asbestos-Associated Disease in the United States. US Department of Labor J-9-M-8-0165. June 1982.

Steinfurth R: Director of Health Hazard Program, International Assoc. of Heat, Frost Insulators and Asbestos Workers. Washington, DC (personal communication, 1980).

Stumphius J: Epidemiology of mesothelioma in Walchern Island. Br J Ind Med 28:59-66, 1968.

Wong O: An epidemiologic study of workers exposed to brominated chemicals: With a discussion of multifactor adjustment. Banbury Report #9, Cold Spring Harbor Laboratory, pp 359-378, 1981.

Verma DK, Middleton CG: Occupational exposure to asbestos in the drywall taping process. Am Ind Hyg Assoc J 41:264-269, 1980.

Zumwalde R: National Institute for Occupational Safety and Health, Cincinnati, OH (personal communication, 1980).